Planning for railway network connectivity and spatial proximity
Balancing node and place functions in Flanders and Brussels Capital Region

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Abstract
In metropolitan areas around the world, the integration of transport and land use developments around railway stations is high on the agenda of governments. Mounting concerns over the adverse effects of mobility systems dominated by individual motorized transport are increasingly translated into policy goals bolstering public transport networks in polycentric metropolitan regions with the overall aim to functionally integrate urban settlements by systematically improving their accessibility. In Flanders, the policy domains of mobility and urban planning have never been firmly attuned. This apparent mismatch has resulted in a dispersed settlement pattern that hinges on, and is mutually enhanced by a mobility system dominated by car use. The preparatory writings for the new Flemish Spatial Policy Plan however recognize and strongly emphasize the importance of mixed-use residential and commercial activities clustered around rail transit hubs in order to master mobility-related problems and improve energy efficiency. This paper investigates the extent to which such network-based synergy has thus far been optimized for the land use transport nexus in catchment areas of the Flemish and Brussels train stations by making use of the node-place model put forward by Bertolini. Building on a selection of accessibility indicators, different approaches to railway network connectivity ('node values') are examined and confronted with geographically detailed data on amenity levels, job and employment densities ('place values'). Drawing on these confrontations, opportunities for (i) land-use densification within catchment areas or (ii) increased network connectivity of the stations can be detected in order to improve levels of non-car based accessibility within the metropolitan region and, ultimately, the sustainability of daily mobility trips.

Keywords*:* "accessibility", "network analysis", "railway stations", "transit oriented development", "land use transport integration", "sustainable development".

1. <u>A sustainable land-use development and transport challenge: the case of Flanders</u>

> *"(…) verschijnt daar onder ons ineens een door een krankzinnige bijeengenaaide lappendeken, God weet van welke afval bijeengeknoeid, en daarop door een woest geworden reus, de inhoud van hele bazars blokkendozen rondgestrooid, met verachting neergesmeten, klinkt het niet dan botst het, om er van af te zijn. Daartussen een warboel van wegen en straatjes, kriskras in alle richtingen, schijnbaar slechts luisterend naar de wet van de angst voor de leegte die, naar men ons geleerd heeft, ook de komposities van de grootste kunstschilders van het landje daar beneden heeft bezeten" (Braem 1968, 19)*[1]

With a great deal of verve, Belgian architect and urbanist Renaat Braem satirized the Flemish post-war spatial chaos and absence of urban planning in his political pamphlet *The most ugly*

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[1] In Belgium, Renaat Braem was probably first in publicly condemning urban sprawl as problematic. We quote him without translation, since the animated gist of his statement would get lost.

country in the world (1968). Although published half a century ago, his animated description of a bird's eye view on the Belgian territory could have easily been written today. Since the publication of Braem's lament, the suburban sprawl-like urban morphology of the northern half of the country (Van Meeteren 2016), or *patchwork randomly sewed together* as Braem sneeringly framed it, has become ever more pronounced and discernible in today's landscape. Particularly the *Flemish Diamond,* which roughly covers the area in between Antwerpen, Gent, Brussel and Leuven, is characterized by a highly dispersed settlement morphology (see Figure 1) interspersed with historical cities and villages (Antrop 2004). Besides Braem's pejorative metaphors, this diffuse urbanity is locally most referred to by urbanists as the *nebular city* (Dehaene and Loopmans 2003; de Vries 2014), representing the drop-like nebula of small to very small villages and interspersed suburban zones on a short distance from one another (De Rynck 2003).

This spatial idiosyncrasy has deep cultural antecedents and strong socio-economic roots (De Meulder *et al*. 1999; Kesteloot 2003; De Decker 2011). While the starting point of Belgium's dense settlement structure can be traced back to the Middle Ages, the 'seeds of total urbanization' were sown towards the end of 19th century (De Meulder *et al.* 1999, 81). Societal changes resulting from the industrial development of the Walloon axis, i.e. the rise of socialist movements and secularization, warned the powers that were, i.e. the bourgeoisie and the Church. New policy tools were implemented to geographically spread the industrializing labour force away from the unhealthy, 'bad' and politically dangerous cities, giving rise to profound anti-urban political and cultural convictions (Kesteloot 2003; De Decker 2011; Meeus *et al.* 2013) that still shape contemporary culture, politics and economic policies (Van Meeteren 2016). Some 'policy tools' included the construction of dense and extensive rail- and tramways of local and regional lines (with the *Nationale Maatschappij voor Buurtspoorwegen* playing an instrumental role), accompanied by a system of exceptionally cheap railway season-tickets for employees. As De Meulder *et al.* (1999, 83) argue: 'The finely meshed railway and tramway network was an efficient political device for countering the urban expansion that typified industrialization in neighbouring countries'. In this way, the proletariat could be conveniently shipped in from the countryside by train or tram on a daily basis, and this in tune with the state of the economy. Other interventions stimulated individual and affordable ownership of new houses that were strictly geared towards the working population, e.g. the first Belgian Housing

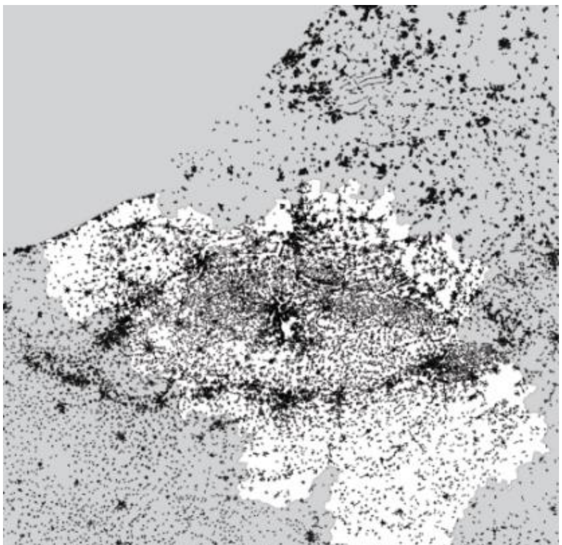

Figure 1 : Development patterns of Belgium and its neighboring countries. The central part shows a diffuse urbanity (source: Blondia *et al.* 2011, 1)

Act (*Loi sur les Habitations Ouvrières*, 1889) and the establishment of the National Society for Small-scale Land Ownership, 1936). Public utilities on the countryside were made more affordable as well. This interplay between housing policy and the systematic politics of mass rail transport had radical consequences for the urbanization of Belgium: 'By inhibiting migration to the cities, the problems of density and congestion that beset such cities as London, Manchester and Berlin could be prevented. The provincial town remained the norm. In the absence of typically metropolitan problems, Belgium never really worked out a real urban policy for itself (including town planning)' (De Meulder *et al.* 1999, 86).

The post-war democratisation of car ownership, De Taeye act (1948) directly stimulating owner-occupied housing, and the overall Fordist circle of wealth creation instigating mass consumption of household products that further facilitate independent housing on the countryside, unleashed a further irreversible housing proliferation process (De Meulder *et al.* 1999). This appropriation of space endures today with an average of 6 hectares per day (Poelmans and Engelen 2014).

Today, this diffuse urbanity hinges on, and is mutually enhanced by, a transport system dominated by car use and ownership. As peripheral development increases distances between origins and destinations, dependency on the car as a flexible mode increases, thereby further facilitating dispersed settlement patterns (Blondia and De Deyn 2012). Substantive fiscal government support for company cars continue subsidizing this dynamic. Due to this car-centred physical reality and mentality, spatial development and public transport are not in tune in many places in Flanders (Lagiewka *et al.* 2016); the critical mass of people to organize a well-functioning public transport system, reminiscent of the once so extensive local and regional tram- and railway network, is today only to a small extent concentrated along strategic places (Verhetsel and Vanelslander 2010; VRP 2016).

This lack of co-ordination between the fields of spatial planning and mobility in Flanders (De Vos and Witlox 2013) is problematic for several reasons. From an ecologic point of view, energy use and emissions related to (daily) mobility and the heating of large, single houses on the countryside (Lagiewka *et al.* 2016), urgently need to decrease given the severity of the climate change problem (Klein 2015). However, increased structural congestion on the Flemish roads (VRP 2016) seems to push the realization of this ambition in the opposite direction. Further, from an economic perspective, inadequate accessibility of cities and economic centres hampers the development of Flanders as an economic top-region. Furthermore, the population of Flanders is expected to grow with 1,2 million inhabitants by 2050, leading to questions regarding the spatial strategy of additional housing and the management of changing mobility demands due to a changing demographic composition (Loris *et al.* 2013).

2. Improving accessibility via railway network connectivity and spatial proximity

A structural part of the solution lies in the shift from an infrastructure-oriented mobility policy to a policy investing in proximity, public transport accessibility and increased quality of life (VRP 2016; Papa *et al*. 2013). According to the White Paper of the new Flemish Spatial Policy Plan (BRV), spatial developments should be increasingly clustered (i) around multimodal public transport hubs and (ii) along transport axes with high job, residential and amenity densities in order to increase the modal share of the most sustainable transport modes today (walking, cycling and public transport) (Ruimte Vlaanderen 2016). The rail network in particular, has a central role to play in this policy change, as it is today "the public transport system with the highest potential to transport many people with a minimal impact on health and a minimal use of space (…) the (re)development of urban centres therefore need to take place in the vicinity of stations within the rail network" (Ruimte Vlaanderen 2016, 72).

These development principles are akin to *transit oriented development* (TOD) (Calthorpe 1993; Cervero 1998): an increasingly popular urban design paradigm in metropolitan regions worldwide (VRP 2016). In this paradigm, the notion of *accessibility* equals the potential for human interaction at and around transit hubs, which is realized through a combination of transit network connectivity *and* spatial proximity and a functional mix of services, jobs and residencies. In contrast with early TOD implementations and research in the United States originating from an urban design context and focusing on single station area development (Calthorpe 1993; Cervero 2004; Dittmar and Ohland 2004), TOD planning in Europe has mainly been practiced and investigated from a *regional* or *network* point of view (Knowles 2012; Bertolini *et al.* 2012; Papa *et al.* 2013). This *Network TOD* or European TOD (Papa *et al*. 2013) aims for the development of a polycentric network of station areas of different size and function in an urban regional context. Under the right conditions, this geographical scale offers "the potential not only to create attractive places in station catchment areas, but in a broader geographical scale, also to shape polycentric cities and regions, mitigate urban sprawl and boost public transport ridership" (Papa *et al.* 2013, 2). Curtis and Scheurer (2016, 8) refer to the interplay of the (intended) network TOD characteristics (e.g. high service frequencies along geographical desire lines, seamless multimodal transfers, integrated ticketing) as the *network effect* of public transport services, where "the ability of the network as a whole to provide accessibility is superior to that of the sum of its individual components".

The main assumption underlying the TOD principle thus implies that energy efficiency, and therefore the sustainability, of daily mobility trips will improve as the potential and attractiveness to make use of high-quality public transport and to travel by bike or foot increase. In the case of Flanders, the empirical research by Verhetsel and Vanelslander (2010) has provided some proof for this assumption as it was demonstrated that people living nearby railway stations, and especially commuters having a job nearby the main railway stations, tend to have more sustainable commuting characteristics. The proximity of bus, tram or metro stops also attracts more users of these modes of transport. They concluded[2] that "future spatial planning strategies that support the location of activities in urban areas and near stations and junctions of public transport, will have positive effects on commuter characteristics, in the sense that inhabitants or workers will move towards more sustainable characteristics" (p. 698).

Improving accessibility thus concerns both transport *and* location policy (Wegener and Fürst 1999). Figure 2a, inspired by the *land use transport feedback cycle* described by Wegener (2004), illustrates the interplay between both policy fields, leaving room for the influence of other potentially 'disturbing' influences such as housing policy, economic policy and environmental policy (Verhetsel and Vanelslander 2010). In the literature several approaches have been devised that further elaborate on this sustainable transport and land use interaction.

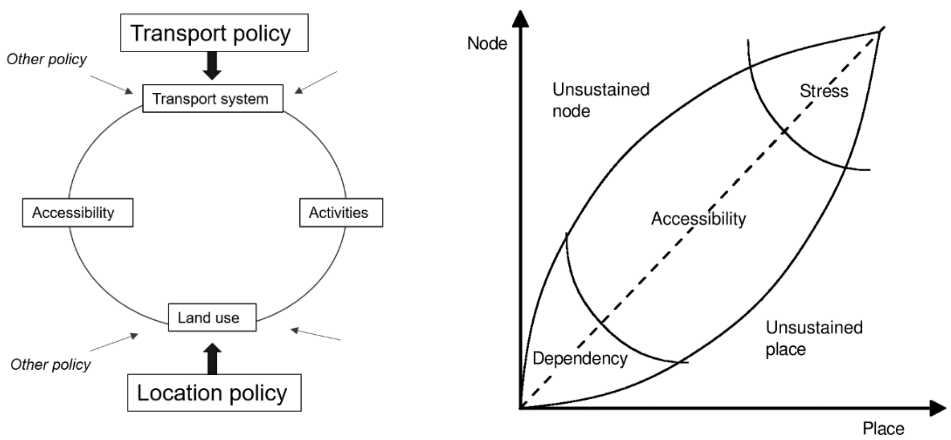

Figure 2 a) Relation between land use and transport (Verhetsel and Vanelslander 2010, 692), b) The node-place model described by Bertolini (1999, 202)

[2] As the authors indicate, this conclusion however needs to be put in perspective as the car is still the most important mode of transport by far, see further elaboration by Verhetsel and Vanelslander (2010, 698).

The node-place model by Bertolini (1999, see Figure 2b) has become one of the leading analytical frameworks to systematically assess (changes in) both dimensions for stations in a public transport network. In this model, *node-values* correspond with the intensity and diversity of connectivity in the transit network and in the vicinity of the transit stop, while *place-values* measure the intensity and diversity of activities and amenities provided. The model is dynamic and "suggests a balance exists or will develop between node and place functions such that in the long term *most* railway stations lie along or tend to approach the diagonal" (Reusser *et al.* 2008, 193, emphasis added). The model thus follows the reasoning of the transport land use feedback cycle, and aims to further explore its underlying relationships with a focus on railway station areas. Railway stations that are situated above the diagonal are places where the potential for physical human interaction has not been fully realized despite a high connectivity in the rail network (*unsustained node*). The *unsustained places*, in turn, represent the opposite situation. A systematic analysis of the positions of different train station areas on the node and place scale can provide insights into their relative functioning and thus help define the scope of further and more geographically detailed inquiries.

3. Objectives and method

The objective of the research on which this paper reports is twofold. *First*, we aim to provide a systematic and methodologically sound overview of aggregated and disaggregated node and place functions for all 285 railway stations in the region of Flanders and the Brussels Capital Region (BCR). While the node-place model has been applied to a plethora of cities and city-regions on different geographical scales (from the national scale to comparative studies of different cities or transit corridors), it has not been operationalized specifically for railway stations on the regional scales of Flanders and the BCR before[3]. Furthermore, building on the data produced in Verachtert *et al.* (2016), a model enhancement through more innovative node functions (based on the SNAMUTS accessibility indicators) and geographically more detailed place functions (compiled of raster data on a scale of 100 by 100 meters) can be obtained.
Second, we aim to interpret the analyses results to tentatively identify the extent to which the network-based synergy has thus far been optimized for the land use transport nexuses of catchment areas for a series of adjacent nodes along two important railway corridors. We hereby specifically focus on the spatial development principles for public transport nodes as outlined in the White Paper BRV.
The method and operationalization of the indicators is explained in more detail below and Figure 3 provides a schematic overview and illustration of the data layers used and the main analytical steps that were taken.

Node functions: different approaches towards public transport network connectivity

Following Bertolini (1999), the node index is a measure of the connectivity of a node in the overall network, with *intensity and diversity of transport supply* being the main criteria. In our approach, and in contrast with Bertolini's original operationalization for the cases of Amsterdam and Utrecht, only *public transport accessibility* is taken into account to calculate the *composite* node index[4]. This choice was made to ensure an unambiguous interpretation of

[3] The research 'Stedenstructuur Vlaanderen' by Sum Research (2013) systematically calculated node and place values, however for *a selection of* Flemish and Brussels *municipalities*. Also, Verachtert *et al.* (2016) published aggregated maps for both dimensions covering the entire regions of Flanders and the BCR, yet the research did not focus on railway stations in particular, nor did it elaborate on statistical analyses between the aggregated and disaggregated indicators.
[4] Bertolini (1999) (and some other operationalizations such as Reusser *et al*. (2008) for railway stations in Switzerland) also include indicators of car accessibility (car parking capacity and distance to the closest highway) and bicycle accessibility (bicycle access and bicycle parking capacity).

the index. When analyzing the disaggregate indicators below, a fourth additional indicator measuring the density of cycling and foot paths within the station areas (i.e. assessing accessibility by slow traffic modes) will however be added to the discussion.
The Spatial Network Analysis for Multimodal Urban Transport tool (SNAMUTS, see Curtis and Scheurer 2010) provides a series of indicators assessing public transport accessibility from different points of view. The tool reasons from the perspective of an every-day user of a city's land use – transport system, taking into account both temporal aspects (e.g. travel time, service intensity), topological aspects (e.g. number of multimodal transfers needed) and structural aspects (e.g. total residential population, average settlement densities). The indicators can be used for the networks of entire metropolitan regions as well as for specifically defined sub-regions or corridors (Curtis and Scheurer 2016). The research recently completed by VITO (Verachtert *et al.* 2016) operationalized and calculated a series of SNAMUTS indicators for all train stations in Flanders and the BCR, based on the characteristics of the public transport network in 2015. This data was transferred by VITO for use in this research. For full methodological details, we therefore refer to Verachtert *et al.* (2016).

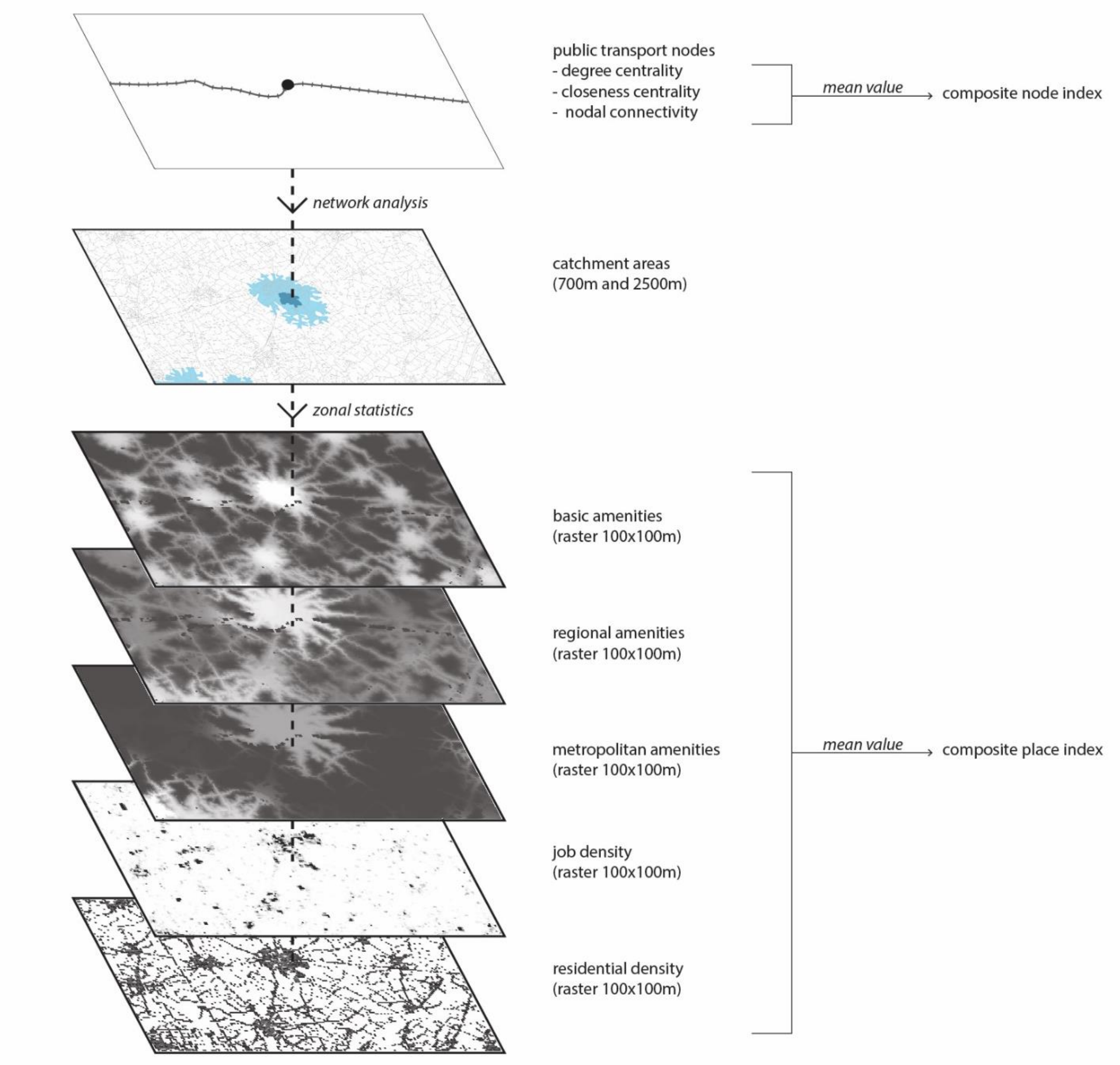

Figure 3: Schematic illustration of the data layers used and the main analytical steps

Three of the SNAMUTS indicators that are focusing on aspects of the public transport network[5] were implemented in this research:

- **Closeness centrality**: describes the spatial properties of a public transport system in terms of travel time and service frequency and was calculated according to:

$C_i = \frac{\sum_{j=1, j \neq i}^{N} L_{min,ij}}{N-1}$ with $L_{min,\,ij}$ = minimum cumulative impediment between nodes i and j with the travel impediment $d_{ij} = t_{ij} / f_{ij}$ (t = travel time, f = service frequency)
N = number of nodes in the network

- **Degree centrality**: describes the topological structure of the network measuring the number of transfers required to make a journey (i.e. transfer intensity or directness of journeys):

$D_i = \frac{\sum_{j=1, j \neq i}^{N} P_{min,ij}}{N-1}$ with $P_{min,\,ij}$ = minimum number of transfers between nodes i and j
N = number of nodes in the network

- **Nodal connectivity**: measures the strength of each activity node for integration of multimodal public transport services. It captures the suitability of activity nodes for making transfers or breaks of journeys with minimal disruption to the flow of movement:

$N_i = \left[\left(\sum_{j=1, j\neq i}^{N(i)} a_{ij}\right) - 2\right]\left[\sum_{k=trein,tram,metro,bus} f_{ki} . cap_k\right]$ with:
$\sum a_{ij}$ = train-, tram-, metro- and bus links converging in node i
N(i) = network nodes adjacent (nearest neighbour) to node i
f_{ki} = number of departures per hour from node i
cap_k = the average capacity of mode k compared to that of a train

The composite node index calculates the mean value of these three indicators for each train station. Figure 4 gives an overview of all nodes on the Flemish and Brussels territory that were incorporated in the calculations. Besides these nodes, calculations also included (i) all railway stations in Wallonia accessible from Flanders or the BCR and (ii) a selection of international railway stations accessible with Belgian trains and within a radius of 325 km from Antwerp-Central station (more details in Verachtert *et al.* 2016, 96).

Place functions: measuring the intensity and diversity of activities in catchment areas

Following Bertolini (1999), the place index is a measure of the *intensity and diversity of activities* taking place in the area around the station. Besides job density and residential density (the focus of most applications of the node-place model), our operationalization extends the range of place functions by including three different types of amenities, aggregated into basic, regional and metropolitan amenities[6]. As each type requires other accessibility standards, this division enables a more diversified insight into the geographical distribution of different kind of amenities around railway nodes. The data regarding job density and the three types of amenities was transferred for use in this research by VITO, while residential density was provided by the Federal Government (office of Home Affairs). The data consists of raster shapefiles on a spatial resolution of 100 x 100 meter and corrections were made for decreasing marginal utility (for details see Verachtert *et al.* 2016, 54). Zonal statistics were then calculated in GIS software to determine mean values per catchment area. The composite place index used in our analysis was calculated as the mean of the individual place indicators.

[5] Other SNAMUTS indicators such as *contour catchment* and *nodal betweenness centrality* measure aspects (i.e. job and residential densities) that overlap with the place functions of this research.
[6] See Verachtert *et al*. (2016, 46 – 64) for an overview of the methodology and lists of amenities per type.

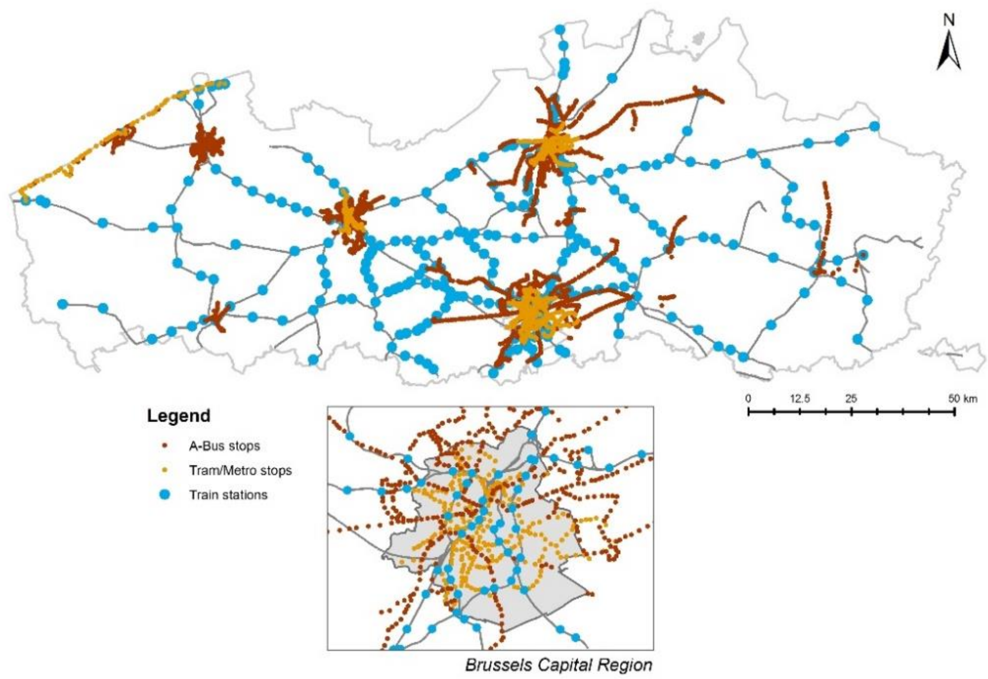

Figure 4: Overview of all Flemish and Brussels PT-nodes included in the calculations

Different approaches exist for delineating the size of these zones of influence, or *catchment areas*, which correspond with walkable (or bikeable) radii to and from railway stations. Most European studies (e.g. Bertolini 1999; Reusser *et al.* 2008; Zemp *et al.* 2011; Vale 2015) adopt a 700 meter radius for catchment areas, while most American and Canadian studies (e.g. Schlossberg and Brown 2004; Atkinson-Palombo and Kuby 2011) opt for ¼ mile (400 m) or ½ mile (800 m) distances. To allow comparison with previous European studies, we adopted the 700 meter walkable radius. In addition, we calculated the statistics for a conventional cycling distance of 2500 meter (i.e. 15 minutes of cycling), since the (electric) bike, cargo bikes and others have become increasingly popular as in- and egress modes in Flanders (VRP 2016). However, as space is limited, this paper will only report on the place measures based on the 700 meter distances.
It is furthermore important to indicate that catchment areas were calculated based on the road network (highways and other road segments not available for pedestrians or cyclists were omitted) and therefore also take into account physical barriers such as waterways. As a corollary, walkable catchment sizes vary considerably with the largest surface (station Mouterij, in the BCR) being almost nine times larger than the smallest (station Brussels National Airport). Variations in cycling areas are much smaller due to the bridging of most obstacles. For some of the nodes at the edge of the Flemish territory (N=20), place values are systematically underestimated as the catchment areas partly exceed the borders with the adjacent areas for which no data was gathered.

4. Balancing node and place functions

The result of the confrontation between the composite node and place indices (700m) is provided in Figure 5 with the stations most distant to the general trend labelled by region (left: BCR, right: Flemish region). The ovals represent the areas where most stations are located according to the general trend. Unsurprisingly, nodes within the upper right quadrant are mainly BCR stations. While the combined plot of all railway stations in Flanders and the BCR clearly exhibits a general balance between node and place indices, the overall relation is far from straightforward. Some general observations can be made here.

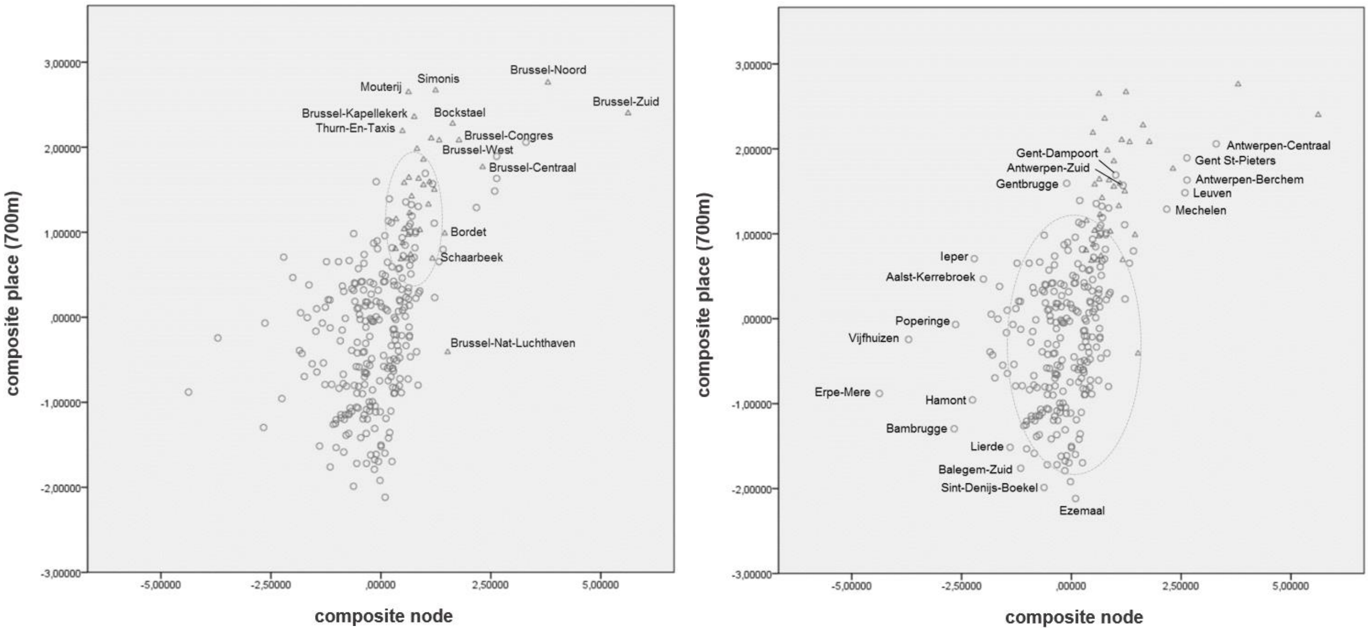

Figure 5: Composite node-place model for all railway stations in the BCR (Δ) and Flanders (o)

First, data points are fanning out when moving along the diagonal towards the lower left and upper right quadrants. This somewhat contrasts with Bertolini's theoretical rugbybal shaped node-place diagram (Figure 2b), as our data suggests that most diversity in both dimensions can be found on the *outer* edges of the plot. For some of the less (and more) connected nodes in the network, diversity and intensity of activities thus vary considerably and vice versa. Second, the distribution of the composite node index strongly resembles a normal distribution while the composite place values are more uniformly distributed. As a result, a vertical data pattern around the point where the z-scores of the node index approach 0 can be discerned. This implies that stations with a similar, average, composite node index are associated with highly varying place values. However, underlying the composite node index are three network indicators with highly differing distributions as well. An analysis on a disaggregated level thus seems imperative in order to better grasp the generic patterns displayed in Figure 5. Table 1 (attached) provides a series of descriptive statistics in the form of Spearman rank correlation coefficients for each combination of indicators. All couples of indicators appear to be statistically significant and most coefficients have moderate to (very) high values.

When examining the coefficients between the individual **node indicators**, *closeness centrality* and *degree centrality* seem to only weakly correlate. Assessing and understanding this relation and its geography allows us to query whether there are prominent mismatches between both properties that can have a disruptive impact on a network's functioning.
Figure 6a therefore visualizes the z-scores of both distributions. The pattern is reminiscent of a weeping willow, with the long vertical branches indicating nodes with exactly the same degree of connection, as they are located along the same railway route and thus require the same number of transfers. Besides the general observation that the BCR stations systematically outperform the others when it comes to closeness centrality (but have a larger internal degree connectivity variation), it is striking to note the isolation of the four stations on the left side of the graph (from lowest to highest closeness centrality: Erpe-Mere, Vijfhuizen, Bambrugge, Aalst Kerrebroek); from a topological perspective, these nodes are disadvantaged because of the many transfers one has to make in order to reach the other nodes within the network. In terms of travel time and service frequency (closeness centrality) as well, these nodes belong to the least accessible ones in Flanders.

The third node indicator, *nodal connectivity*, is strongly positively skewed (see Figure 6b) since railway stations that are not connected with the alternative public transport modes (see also Figure 4) automatically get a null value. While the most important bus connections in terms of intrinsic potential (the A-lines, as defined by De Lijn, see Verachtert *et al*. 2016, 11) are included in the calculation, the lack of other bus services oversimplifies the nodal connectivity output with too much railway stations (N=177) having an uninformative null value; e.g. it is illogic to note Roeselare railway station having a lower (zero) nodal connectivity than some peripheral nodes in the vicinity of Antwerp such as Hemiksem or Hoboken-Polder. The indicator however still adds meaning to the composite node index, as embeddedness of a railway station in a tram or metro network of course increases a station's accessibility notably, a feature of particular importance for all nodes within the BCR.

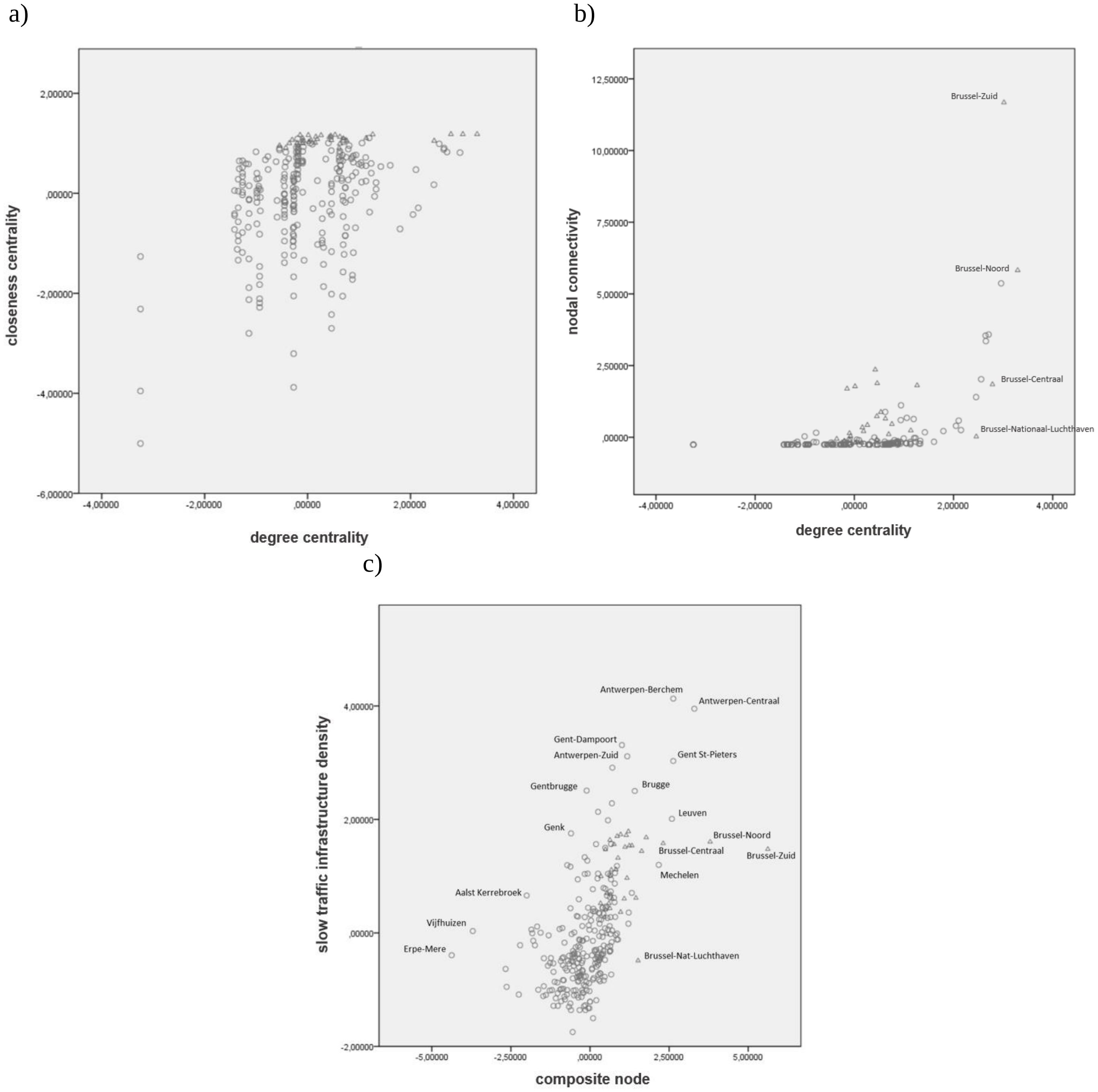

Figure 6: Confrontations between different aspects of transport accessibility in the BCR (Δ) and Flanders (o)

Besides the centrality of a station within the public transport network, sustainable accessibility is also determined by the density of slow traffic infrastructure (cycling paths and footpaths) (Bertolini 1999; Reusser *et al.* 2008). Since such a measure was recently calculated in Verachtert *et al.* (2016) for all train stations (based on catchment areas with a radius of 3,75 km) in Verachtert *et al*. (2016), the confrontation between network connectivity (the composite node index) and slow traffic infrastructure density can be made (see Figure 6c). This confrontation is particularly interesting as it reveals the poor provision of slow traffic infrastructure around the three most connected stations of the network (respectively Brussel-Zuid, Brussel-Noord and Brussel-Centraal). The Antwerpen and Gent stations on the other hand appear very accessible by foot and bike, while Mechelen and Leuven somewhat lag behind when compared to other nodes with a similar network centrality.
While it is beyond the scope of this paper to systematically examine relations between these node indicators for *all* nodes in the network, these confrontations between multiple and different dimensions determining transport accessibility clearly prove useful in addressing the ultimate coordinating objective of this research project (i.e. improving levels of non-car based accessibility within Flanders and the BCR).

As elaborated in the second part of this paper, the geography and functional mix of the subjects instigating the demand for mobility (jobs, amenities etc.) co-determine the accessibility of railway stations. Therefore, the composite place index is also decomposed and interpreted in a similar way. When examining the correlations for the individual **place indicators** (see Table 1), the highest correlation occurs between the residential density and the provision of basic amenities. This is a logic result since higher residential densities strongly increase the demand for amenities organizing daily life and participation in society. The strength of the relation slightly decreases between residential density and respectively regional and metropolitan amenities. A similar, yet less pronounced observation holds for the relation between job density and the three types of amenities, which is also logic given that job densities depend less on the distribution of amenities than residential densities. It is however interesting to discern which station areas are functionally most geared towards employment, which towards housing, and which towards both. Figure 7 therefore combines the indicators residential density and job density for the 700 meter catchment areas.

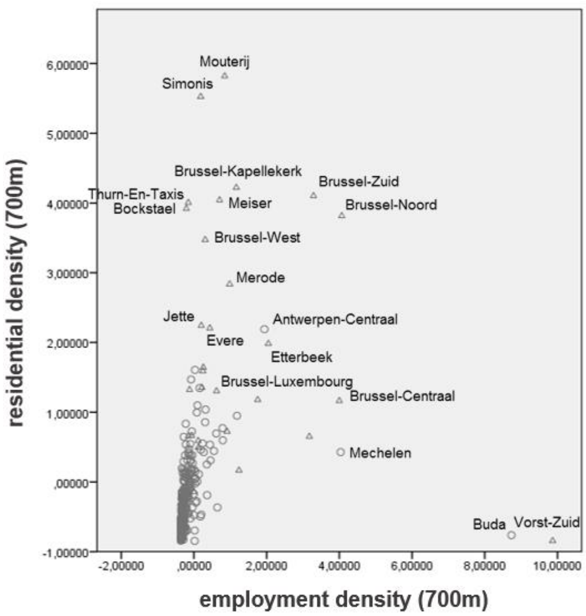

Figure 7: Plot of residential and job densities within the catchment areas

In general, the BCR stations exhibit the highest overall job and residential densities. Some station areas function almost solely as residential zones, such as Simonis or Mouterij, while others are particularly geared towards employment, i.e. Vorst-Zuid or Buda (both just outside the BCR), located in the vicinity of each other. A clear distinction between the three most connected nodes in the network (Brussel-Zuid, -Noord and -Centraal) is revealed as well; while the three station areas have similar job densities, Brussel-Noord and -Zuid clearly host more inhabitants in their vicinity than Brussel-Centraal. Irrespective of the exact comparisons made, it is clear that both distributions are strongly positively skewed and that the majority of station areas exhibit a balance between both dimensions.

To conclude, some combinations between the **node and place** indicators are made with a particular focus on the spatial development principles outlined in the preparatory documents for the BRV. According to Ruimte Vlaanderen (2016, 53, own translation) "the international and metropolitan public transport nodes with a high node value and a high provision of amenities that are furthermore strategically located within the Flemish urbanized space, are selected as the sites with the highest spatial development potential". It is explained in the document that *strategically located* implies the central part of Flanders, together with the (cross-bordering) metropolitan regions of Kortrijk-Lille and Hasselt-Genk-Maastricht, and the region of Brugge (see also Van Meeteren *et al*. 2013). According to the document, these strategic areas compose the region's economic *spatial backbone* and they need to become more integrated by means of a high-quality metropolitan public transport system in order to increase attractiveness and accessibility hence consolidate the competitiveness of Flanders and the BCR in the global economy. Based on both criterions, i.e. (i) being strategically located and (ii) having high node-place values, a schematic map of the railway stations that are considered as *strategic metropolitan areas* according to our operationalization and the principles put forward in the White Paper, is provided in Figure 8 (as for the second criterion, we opted for a cut-off z-score of 1 on both dimensions in the composite node-place diagram). Within this set of highly accessible nodes, Ruimte Vlaanderen (2016, 73) distinguishes between *international* and *metropolitan* nodes to account for different development demands[7].

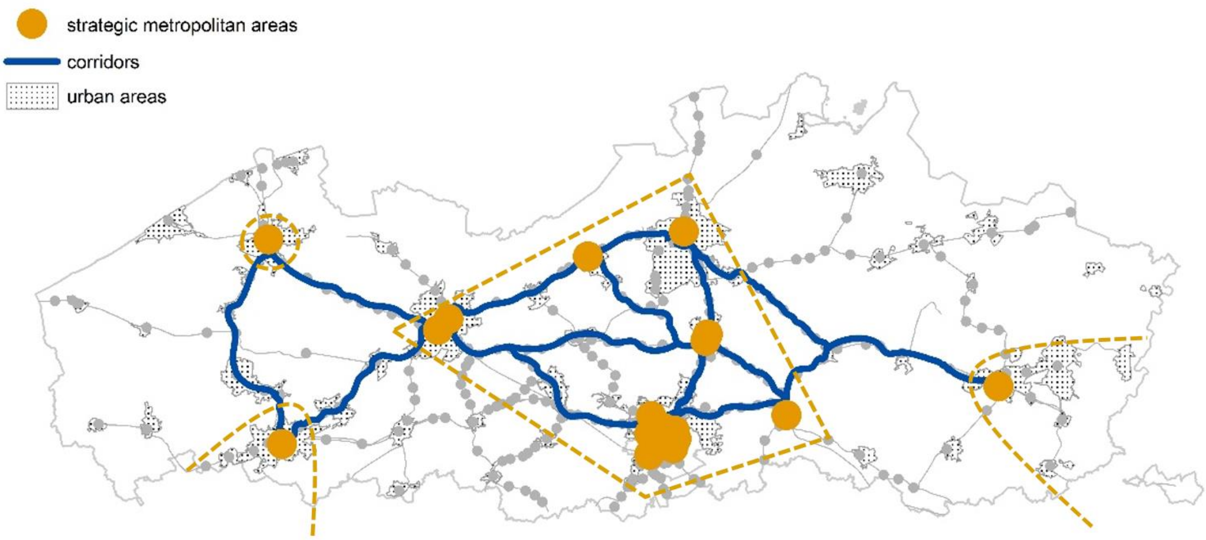

Figure 8: Schematic map of tentative strategic metropolitan areas with indication of the connecting corridors

[7] For instance, developments around the international nodes should be particularly geared towards international amenities and the knowledge economy while metropolitan nodes should focus more on housing and metropolitan amenities (Ruimte Vlaanderen, 2016, 72).

According to the White Paper, a select number of additional nodes should be identified *along* the public transport corridors connecting these metropolitan core areas. Ruimte Vlaanderen (2016) distinguishes two types: *urban-regional* (UR) and *rural-regional* (RR) nodes. It is indicated in the report that these strategic locations need to be easily accessible both by rail and cycling infrastructure (with the interprovincial *fietsostrade*[8] system playing an instrumental role), and that they are considered the future subject of more compact spatial development and/or increased public transport connectivity (Ruimte Vlaanderen, 2016, 151). A sensible next research step thus exists of a more detailed analysis of the disaggregated indicators on the scale of these *corridors*, see Figure 8 (only the fastest connections were considered), in order to select potential UR and RR nodes. As the White Paper does not exemplify the precise distinction between both regional types (i.e. the rural versus the urban character of regions), we chose to use the *demarcation of urban areas* as determined by the Ruimtelijk Structuurplan Vlaanderen (RSV, version 2016/09/05, see Figure 8) as a criterion for stations within an ‘urban region’.
Since it is beyond the scope of this paper to systematically report on the results of *all* corridor analyses, we below illustrate and examine the possibilities of this approach for two corridors: Gent – Antwerpen and Gent – Brussel. Future research will deal with a more in-depth analysis of this research direction. Figures 9a and 9b (see attached) consist of a chronological sequence of stations when travelling along both corridors together with their respective z-scores on all disaggregated indicators (z-scores were calculated relative to *all* stations in the network).

Corridor Gent – Antwerpen

A notable feature of this corridor is the high diversity of station profiles. While origin and destination nodes Gent-Dampoort and Antwerpen-Zuid exhibit much similar characteristics and, unsurprisingly, score high or moderate on all indicators, the z-scores of the stations in between highly vary. For some stations, node and place indicators appear to be more or less out of tune (i.e. Sinaai, Belsele, Nieuwkerken-Waas, Beveren and Zwijndrecht). Others, such as the stations Beervelde and Melsele exhibit an overall (negative) balance, with predominantly negative z-scores, indicating a low overall accessibility of amenities, jobs and housing. Sint-Niklaas and Lokeren station on the other hand, predominantly score positive on all indicators, indicating a rather strong accessibility. It is particularly interesting to note both stations scoring high on the degree centrality measure, even when compared to Gent-Dampoort and Antwerpen-Zuid. Of the three network centrality measures, degree centrality is perhaps the most structural measure in the sense that long-term effort and much resources are required if changes are to be realized. After all, adjusting, or constructing new, railway infrastructure is a more long-term and costly intervention when compared to changes in service frequency or the intensification of connections with other public transport modes. The favourable topological positions of the Lokeren and Sint-Niklaas stations in the network could therefore be regarded as being particularly beneficial for future, more compact, spatial developments. Slow traffic accessibility is however poor compared to nodes with a similar network connectivity. As for Lokeren station, a moderate provision of amenities is present within walking distance and residential density is fairly low. As a corollary, and based on our data, Lokeren station has the theoretical potential to balance this beneficial topological position in the rail network with the realisation of more residential units and basic and regional amenities within walkable (and bikeable) distances from the station. Lokeren station is furthermore strongly embedded within the cycle highway network, as it is served by four directions. Given its overall strategic position, Lokeren station is therefore selected as a potential UR-node.

[8] The Flemish Government and its provinces engaged in rolling out a high-quality, standardized, cycling highway system connecting cities across the region (www.fietssnelwegen.be). A large part of these F-routes are, or will be, located along railway lines, ensuring additional sustainable connectivity between stations.

Corridor Antwerpen – Brussel

Compared to the previous cross-section, this corridor is composed of stations with predominantly positive z-scores, indicating a moderate to high overall accessibility and an overall positive balance between node and place dimensions. A notable observation is the influence of the metropolitan region of Antwerpen which is clearly observable until Hove station, with high and stable provisions of all three types of amenities, yet also with a clearly decreasing slow traffic accessibility. Given the strategic location of these stations within short commuting distances to Antwerpen, and their high provision of amenities and moderate to high residential densities, it would be interesting to examine the possibilities for even more compact development within walkable or bikeable distances in these areas. We therefore select these four stations as potential UR-nodes. The Kontich, Duffel and Sint-Katelijne-Waver stations exhibit somewhat moderate scores, with a relative undersupply of basic amenities in the case of the latter. The two Mechelen stations on the other hand have very similar high levels of amenities and slow traffic accessibility. From a transport accessibility perspective, Mechelen station is clearly more connected in the public transport network. The station area is also characterized by a high job density (with Arsenaal, the central workplace of the NMBS located at the backside of the station). Next, the node and place indicators of stations Weerde and Eppegem exhibit a disturbed balance; both have a rather good transport accessibility but have a relative undersupply of amenities and residential and job densities. Eppegem station is located on the edge of the village centre, explaining its relative deficit of basic and regional amenities and housing. As both nodes are located along the strategic Antwerpen-Brussel axis (Van Meeteren *et al.* 2015) and there is a clear potential for increasing the place values of these catchment areas, we select both as potential RR-nodes. Vilvoorde station exhibits an overall positive balance, while Buda station area is clearly profiled as an employment centre, exhibiting the highest job density of catchment areas in Flanders (see also Figure 7). The station is not staffed, and the area is clearly not adjusted to residential functions. Schaarbeek station on the other hand, is characterized by a high residential density but appears to be somewhat undersupplied with basic and regional amenities.

5. Conclusion

In this paper we presented a systematic assessment of the disaggregated node and place indicators for all train stations and their catchment areas within the Flemish and Brussels rail network, building on the data produced in Verachtert *et al.* (2016). We found that the three SNAMUTS indicators each added particular value to our overall assessment of public transport accessibility and that the geographically detailed data on different types of amenities, job and residential densities ensured a highly accurate model output. Based on the spatial policy principles outlined in the BRV White Paper (Ruimte Vlaanderen 2016), we also illustrated how the (corridor) analyses presented in this paper could be instrumental in identifying railway station areas that are susceptible for more compact spatial development and/or an increased connectivity in the public transport network. Along the Gent-Antwerpen corridor, station Lokeren was identified as a tentative UR-node given its strategic topological position both in the rail and cycling highway networks and its already moderate provision of amenities within walking distance. Potential UR-nodes along the Gent-Brussel axis include the suburban stations within convenient commuting distance of Antwerp (i.e. Mortsel, Mortsel-Oude God, Mortsel Liersesteenweg and Hove), potential RR-nodes include the stations Eppegem and Weerde. In the coming months this research direction will be further expanded in order to arrive at a comprehensive set of strategically located nodes, by means of consultation with Ruimte Vlaanderen and other expert stakeholders in relevant sub-domains (i.e. spatial planning, mobility, housing, public transport, regional economics, public administration). Based on the outcomes of this visioning evidence-informed planning exercise, a selection of station areas will be retained that exhibit different accessibility profiles and have different (theoretical) development perspectives as the subject of more intensive, qualitative, examination.

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Attachments

Table 1: Correlations between the disaggregated node and place indicators

Correlations

			Closeness Centrality	Degree Centrality	Nodal Connectivity	BasicAmenities_700	RegionalAmenities_700	MetropolitanAmenities_700	JobDensity_700	ResidentialDensity_700
Spearman's rho	Closeness Centrality	Correlation Coefficient	1,000	,345**	,543**	,319**	,434**	,513**	,347**	,338**
		Sig. (1-tailed)		0,000	0,000	0,000	0,000	0,000	0,000	0,000
		N	285	285	285	285	285	285	285	285
	Degree Centrality	Correlation Coefficient	,345**	1,000	,618**	,443**	,417**	,367**	,443**	,411**
		Sig. (1-tailed)	0,000		0,000	0,000	0,000	0,000	0,000	0,000
		N	285	285	285	285	285	285	285	285
	Nodal Connectivity	Correlation Coefficient	,543**	,618**	1,000	,552**	,590**	,571**	,586**	,556**
		Sig. (1-tailed)	0,000	0,000		0,000	0,000	0,000	0,000	0,000
		N	285	285	285	285	285	285	285	285
	BasicAmenities_700	Correlation Coefficient	,319**	,443**	,552**	1,000	,828**	,691**	,733**	,905**
		Sig. (1-tailed)	0,000	0,000	0,000		0,000	0,000	0,000	0,000
		N	285	285	285	285	285	285	285	285
	RegionalAmenities_700	Correlation Coefficient	,434**	,417**	,590**	,828**	1,000	,840**	,712**	,758**
		Sig. (1-tailed)	0,000	0,000	0,000	0,000		0,000	0,000	0,000
		N	285	285	285	285	285	285	285	285
	MetropolitanAmenities_700	Correlation Coefficient	,513**	,367**	,571**	,691**	,840**	1,000	,577**	,633**
		Sig. (1-tailed)	0,000	0,000	0,000	0,000	0,000		0,000	0,000
		N	285	285	285	285	285	285	285	285
	JobDensity_700	Correlation Coefficient	,347**	,443**	,586**	,733**	,712**	,577**	1,000	,738**
		Sig. (1-tailed)	0,000	0,000	0,000	0,000	0,000	0,000		0,000
		N	285	285	285	285	285	285	285	285
	ResidentialDensity_700	Correlation Coefficient	,338**	,411**	,556**	,905**	,758**	,633**	,738**	1,000
		Sig. (1-tailed)	0,000	0,000	0,000	0,000	0,000	0,000	0,000	
		N	285	285	285	285	285	285	285	285

**. Correlation is significant at the 0.01 level (1-tailed).

Figure 9: Z-scores of the disaggregated indicators for the stations along the a) Gent-Antwerpen corridor, b) Gent-Brussel corridor